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Recovery of the Macrobenthos at a Dredge Site in Yaquina Bay, Oregon

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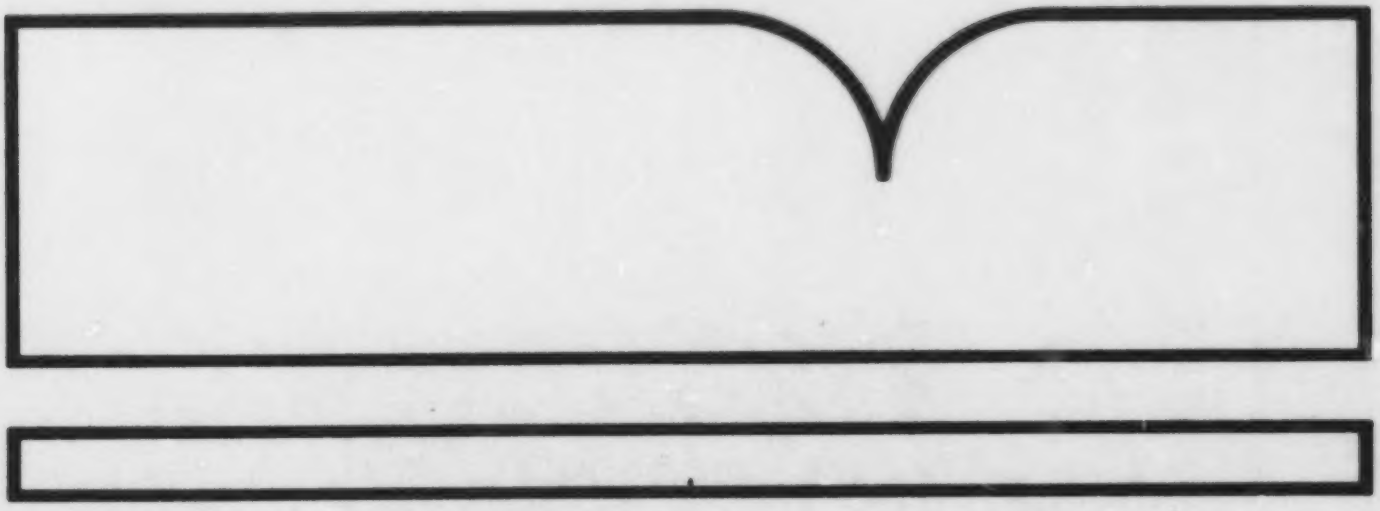

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CHAPTER 20

RECOVERY OF THE MACROBENTHOS AT A DREDGE SITE IN YAQUINA BAY, OREGON

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INTRODUCTION

Knowledge of the resilience of biological communities is important in assessing the ecological consequences of human disturbances in the marine environment [1-3]. Biological recovery partly depends on the kind and degree of perturbation. This chapter deals with the resilience of the benthos following sediment defaunation by dredging and addresses a physical, nontoxic disturbance whose ecological effects can be compared with those of other kinds of pollution that involve chronic chemical contamination.

A small dredging operation in Yaquina Bay, Oregon in October of 1975 provided an opportunity to monitor the temporal pattern of the recovery of a disrupted macrobenthic community. Our survey was designed to test four hypotheses. First, all segments of the macrobenthos are equally susceptible to dredging. Areal species richness and the density of individuals of all species are markedly reduced by this form of disturbance. Second, opportunistic species numerically dominate the benthos during the early phases of recolonization. We expected these opportunists to include the stress-tolerant polychaetes *Capitella capitata* and *Armandia brevis*, both of which were present at our survey site before the dredging occurred. Third, the decrease in species richness and the appearance of the opportunists cause major changes in structural indices

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of community "health," specifically a decrease in information-theoretical diversity and an increase in dominance. Fourth, the final phase of recolonization will involve the disappearance of the opportunists and a rapid reestablishment of the predredging assemblage. Because the dredged area was relatively small, adjacent to unaffected benthic assemblages and not chemically contaminated, we expected complete recovery to be evident within a few months. Testing the last hypothesis was confounded by unanticipated disturbances associated with the continuous presence of a research vessel over the dredge site during the first half of 1976, and a second dredging in September of 1976. However, we continued the survey until the benthos had recovered from the second dredging.

MATERIALS AND METHODS

The dredged site is immediately adjacent to the Oregon State University dock on the south shore of lower Yaquina Bay, Oregon (Figure 1). The dock is about 2.9 km from the seaward entrance of the Yaquina Bay jetties. The dredging was necessary to accommodate the R/V Wecoma, which has a slightly deeper draft (4.9 meters) than other ships in the university's oceanographic fleet. From October 20-27, 1975, an average 0.5 meter of sediment was removed by a clam shell dredge from an area extending 60 meters along and 12 meters off the dock. The area was dredged again from September 20-27, 1976. Together, the two dredgings removed about 1 meter of sediment from the five benthic sampling sites located near the center of the dredged area (Figure 1). After dredging, the water depth from mean lower low water at the dock was 6.1 meters. The water depth at the edge of the Yaquina Bay channel (45 meters off the dock) was about 10.7 meters.

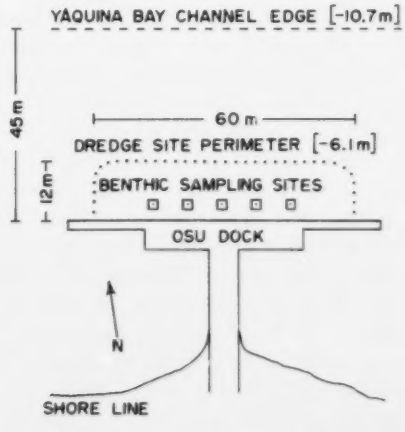

Figure 1. Dredged area and benthic sampling sites near the Oregon State University dock in Yaquina Bay. Water depths from mean lower low water are given in brackets.

Fourteen benthic collections were made at the dredge site between September 26, 1975 and October 17, 1977 (Table I). The first dredging occurred between surveys 2 and 3; the second between surveys 8 and 9. A third human disturbance that apparently affected the benthos was associated with the presence of the R/V Wecoma at the dock during her refitting in the first half of 1976, between surveys 5 and 6.

Table I. Survey Number and Date of Benthic Collections at the Yaquina Bay Dredge Site

1975	1976	1977
1. September 26	R/V Wecoma present, January-June	11. February 11
2. October 7	6. June 16	12. June 27
First dredging, October 20-27	7. August 12	13. August 2
3. October 29	8. September 17	14. October 17
4. November 17	Second dredging, September 20-27	
5. December 23	9. October 1	
	10. November 17	

On each survey, a 0.1-m^2 Smith-McIntyre grab sample was taken at each of the five benthic sampling sites shown in Figure 1. A core (3-cm diameter, 6-cm depth) was taken from each grab for sediment particle size analysis. The size distribution was determined for sand by sieving through a Wentworth scale screen series, and for the silt-clay fractions by the pipette method [4]. Animals were removed from the remainder of the grab sample by sieving the sediment through 1.0- and 0.5-mm screens, preserved in 10% buffered formalin, later transferred to 70% ETOH, identified to the species level and enumerated. The community structure analysis was based on specimens retained on the 1.0-mm screen. Specimens from the 0.5-mm screen were included in the analysis of size frequency distribution of selected species.

For the biological and sediment analyses, the five grabs collected in each survey were treated as replicates and the results expressed as mean values per 0.1-m^2 grab. Areal species richness and density were calculated as the mean number of species (S) and number of individuals (N) collected per 0.1 m^2 of bottom area. The complement of Simpson's [5] index (S.I.) was used as a measure of dominance that is positively related to diversity:

$$1 - \text{S.I.} = 1 - \sum_{i=1}^{S} \frac{n_i(n_i - 1)}{N(N-1)}$$

where S and N = number of species and individuals, respectively, in the sample, and
n_i = number of individuals of the i^{th} species.

Shannon's equation was used as a measure of information-theoretical diversity (H') that is sensitive to both species richness and dominance [6].

$$H' \cong \frac{1}{N}\left(N \log N - \sum_{i=1}^{S} n_i \log n_i\right)$$

Both normal and inverse numerical classifications were applied to the biological data set [7]. The normal classification clusters samples on the basis of similarity in the composition and relative abundance of species. Inverse classification clusters species on the basis of similarity in distribution among samples. To reduce the data set to a manageable size, rare species represented by less than 10 individuals in the total survey were excluded from the classification. The Bray-Curtis dissimilaritv coefficient was used in the normal classification:

$$D_{jk} = \frac{\sum_i |x_{ij} - x_{ik}|}{\sum_i (x_{ij} + x_{ik})}$$

where D_{jk} = dissimilarity between collections j and k, and
$x_{ij(k)}$ = the number of individuals of the i^{th} species in the j(k) collection.

Prior to the inverse classification, the abundance of each species in each collection was standardized by dividing it by the species' mean abundance in all collections. This standardization permits a close affinity between species that differ in abundance but have similar distributions among the collections. The Bray-Curtis coefficient was used in the inverse analysis with the following changes:

D_{jk} = dissimilarity between species j and k, and
$x_{ij(k)}$ = the mean standardized abundance of species j(k) in the i^{th} collection.

Once the matrix of dissimilarity values was generated, the collections (or species) were clustered to form a dendrogram. In this process, all entities beginning with the least dissimilar were combined in a hierarchial fashion. This procedure requires a sorting strategy to determine the dissimilarity between a newly combined pair of entities and all other entities remaining in the matrix. The method we used is the flexible sorting strategy of Lance and Williams [8]:

$$D_{hk} = 0.625(D_{hi} + D_{hj}) - 0.25\, D_{ij}$$

where entities i and j are fused to form group k,

D_{hk} = dissimilarity between group k and entity h,

$D_{hi(j)}$ = dissimilarity between entities h and i(j) in the matrix prior to fusion of i and j, and

D_{ij} = dissimilarity between i and j before they were combined.

RESULTS

Sediment Particle Size Distribution

Fine sands accounted for 50% or more of the sediment weight on all sampling dates. Before the first dredging, the sediment particle size distribution around the fine sand modal class was positively skewed toward very fine sands, silts and clays, which, when combined, accounted for 30.6% of the total sediment weight (Figure 2). After dredging, the proportion of very fine sands and smaller particles decreased to 4.8% and the distribution became negatively skewed toward particles larger than fine sands. There was little change in this pattern until after the second dredging in late September of 1976. From November 1976 (survey 10) until October 1977 (survey 14) the proportion of finer particles gradually increased to 25.6% and the distribution became negatively skewed (Figure 2).

Macrobenthos

Density and Diversity

Temporal patterns were quite similar for both areal species richness and the density of individuals in the entire assemblage (Figure 3). The mean number of species collected per 0.1 m^2 grab decreased after the first dredging (October 1975) from 33.6 to 17.4. Species richness increased in November and December 1975 to about 26 species/0.1 m^2, but dropped substantially during the presence of the R/V Wecoma in the first half of 1976. A mean of only 13.2 species/0.1 m^2 was observed in later June 1976 after the ship had completed its refitting and gone to sea. By September 17, 1976, richness had increased to 26.0 species/grab. The second dredging (late September 1976) reduced richness to 11.6 species/0.1 m^2, the lowest level recorded in our study. Between fall 1976 and summer 1977 areal species richness gradually returned to levels that existed before the first dredging. Similarly, the density of the entire macrobenthos assemblage dropped after the first dredging from 711.4 to 140.4 individuals/0.1 m^2 (Figure 3). Slight recovery was evident in the fall of 1975, but a mean of only 60.6 specimens/0.1 m^2 were collected after the departure of the R/V Wecoma.

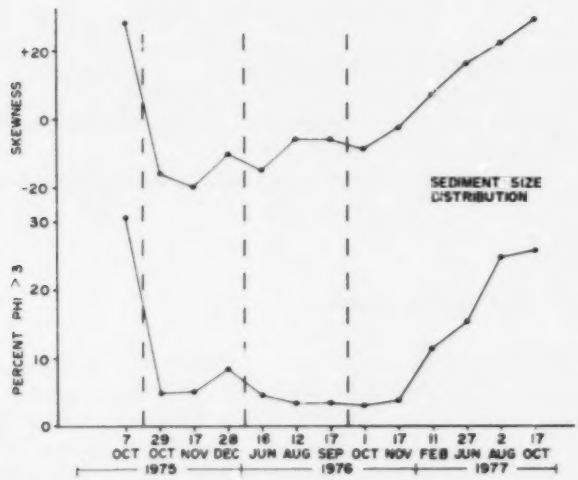

Figure 2. Temporal changes in the proportion of very fine sands and smaller particles (phi >3) and the skewness of the particle size distribution of sediment samples at the Yaquina Bay dredge site. Vertical dashed lines represent (in chronological order) the first dredging, presence of the R/V Wecoma and second dredging.

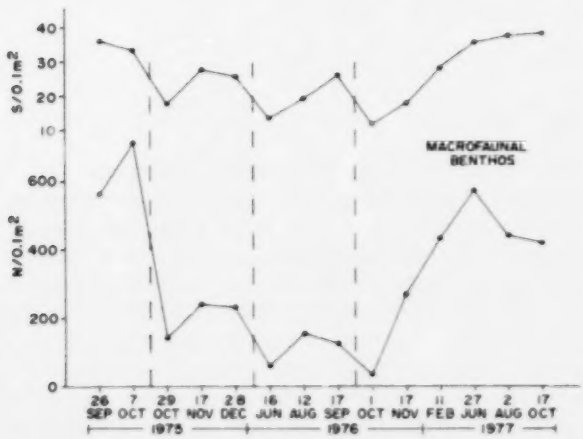

Figure 3. Temporal changes in areal species richness (S/0.1 m^2) and number of individuals (N/0.1 m^2) in the macrofaunal benthos at the Yaquina Bay dredge site. Vertical dashed lines represent (in chronological order) the first dredging, presence of the R/V Wecoma and second dredging.

Density increased slightly in the summer of 1976 and then dropped to its lowest value (36.4 individuals/grab) after the second dredging. As in the case of areal richness, density did not approach its initial predredging level until the summer of 1977.

The temporal changes in density were not due to the dynamics of a few abundant species, but rather reflected the behavior of most species in the assemblage. We divided the 165 species collected in the survey into three groups based on a ranking by mean density in all collections. The groups included the 10 most abundant, 11-30 most abundant and 135 least abundant species. These correspond roughly to abundant, common and rare species groups. The temporal pattern in the density of each group was very similar to that of the entire assemblage (Figures 3 and 4).

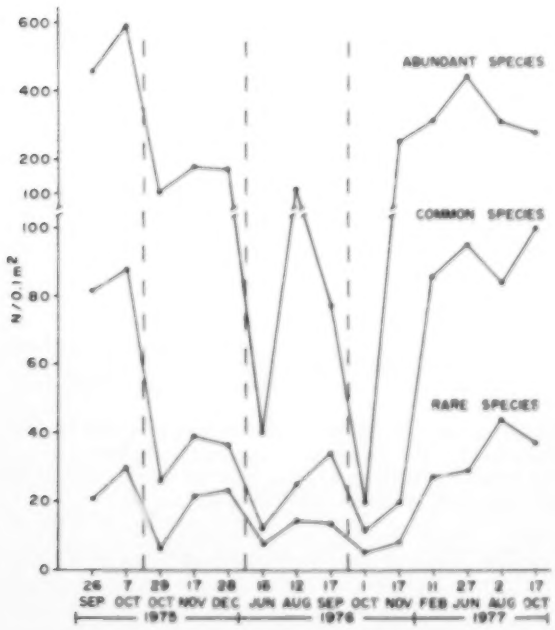

Figure 4. Temporal changes in the combined density of the 10 most abundant, 20 common and 135 rare benthic species at the Yaquina Bay dredge site. Vertical dashed lines represent (in chronological order) the first dredging, presence of the R/V Wecoma and second dredging.

Temporal changes in the information-theoretic diversity index (H′) and the complement of Simpson's [5] index of dominance were very similar to one another, but distinctly different from the patterns of density and areal richness (Figure 5). The indices of diversity and dominance generally decreased immediately after both dredgings and the presence of the R/V Wecoma, but the changes were not as marked as those of richness and density. The dominance and diversity indices equalled or slightly exceeded their initial predredging values on November 17, 1975 and September 17, 1976. On the same dates, density and areal richness were well below predredging conditions (Figure 3). The greatest difference in the diversity-dominance and richness-density patterns occurred after the second dredging. While richness and density reached minimum values on October 1, 1976 and then gradually increased to their baseline levels, diversity and dominance showed a major reduction between October 1 and November 17, 1976. Diversity and dominance values for the collection made on February 11, 1977 were still below the range observed prior to the second dredging. They returned to their initial level during the summer of 1977.

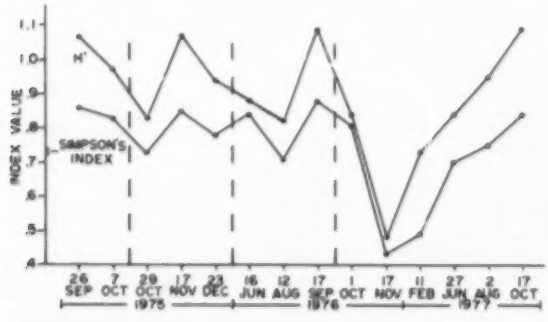

Figure 5. Temporal changes in information-theoretic diversity (H′) and the complement of Simpson's index of dominance for the macrofaunal benthos at the Yaquina Bay dredge site. Vertical dashed lines represent (in chronological order) the first dredging, presence of the R/V Wecoma and second dredging.

The immediate effect of the two dredgings and the presence of the R/V Wecoma on the structure of the benthic assemblage was examined through a t-test for significant differences in mean index values for collections made immediately before and after each perturbation (Table II). Changes in the indices of diversity and dominance were never statistically significant. Both species richness and the density of the macrobenthos decreased significantly after each of the three perturbations. The proportional changes in density and

Table II. Richness, Density, Diversity and Dominance of the Benthos Immediately Before and After Three Perturbations at the Yaquina Bay Dredge Site

Index	Mean Index Values and Statistical Comparison											
	First Dredging				R/V Wecoma Presence				Second Dredging			
	Before	After	t-Test	% Change	Before	After	t-Test	% Change	Before	After	t-Test	% Change
Richness of Species, S/0.1 m^2	33.6	17.4	a	-48	25.4	13.2	a	-48	26.0	11.6	b	-55
Density of Individuals, N/0.1 m^2	711.4	140.4	a	-80	232.8	60.6	a	-74	126.0	36.4	b	-71
Diversity, H'	0.97	0.83	NS	-14	0.94	0.88	NS	-6	1.01	0.84	NS	-17
Dominance, 1-Simpson's Index	0.83	0.73	NS	-12	0.78	0.84	NS	+8	0.88	0.81	NS	-8

[a] $P < 0.01$.

[b] $P < 0.05$, NS, not significant.

richness were very similar, even though initial values differed considerably. The reduction in richness varied from 48% to 55% and for density from 71% to 80%.

Classification

The normal classification divided collections into two major clusters (Figure 6). One cluster includes surveys 3 through 9, i.e., the first collection after the first dredging through the first collection after the second dredging. All of these samples showed a reduction in the density and richness of the benthic assemblage. The second cluster includes the two collections made before the initial dredging and those made during the recovery of the benthos after the second dredging. The arrangement of the collections within the second cluster indicates a temporal sequence during recovery. Collection 14 is most closely related to the two initial predisturbance samples. Thus, by October 1977 the structure of the community was very similar to the baseline condition. The other two pairs of collections, 10-11 and 12-13, represent initial and intermediate stages of recovery, respectively.

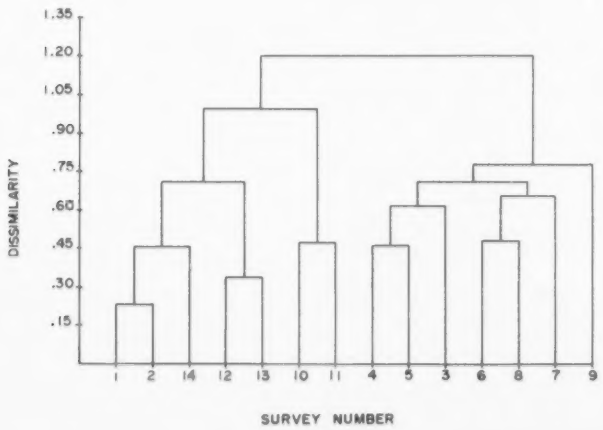

Figure 6. Normal classification of macrofaunal benthic samples from the Yaquina Bay dredge site.

Three major species groups were evident in the inverse classification (Table III). A two-way analysis of the density of the species groups in the collection groups is shown in Table IV. The density of species groups 1 and 2 was greatly reduced during the period of maximum disturbance (surveys 3-9). Group 1

Table III. Three Major Species Groups Indicated by the Inverse Classification of the Macrofaunal Benthos of the Yaquina Bay Dredge Site

Species Group 1	Species Group 2	Species Group 3
Ampharete sp. 1	*Anaitides williamsi*	*Aglaja diomedea*
Amphitrite lacertosa	*Cancer magister*	*Amaena occidentalis*
Cancer productus	*Cancer oregonensis*	*Anisogammarus pugettensis*
Capitella capitata	*Crangon nigricauda*	*Armandia brevis*
Caprella californica	*Harmothoe imbricata*	*Corophium oaklandense*
Chone ecaudata	*Littorina scutulata*	*Diastylis alaskensis*
Cirratulus cirratus	*Lumbrineris zonata*	*Hinnites multirugosus*
Cistenides brevicoma	*Macoma inquinata*	*Hippomedon denticulata*
Clinocardium nuttallii	*Melita dentata*	*Lacuna sp. 1*
Eteone longa	*Mytilus edulis*	*Lamprops quadriplicata*
Eupolymnia crescentis	*Nassarius mendicus*	*Macoma balthica*
Gemma gemma	*Odostomia phanea*	*Paraphoxus epistomus*
Glycinde picta	*Olivella pycna*	*Parapleustes pugettensis*
Haploscoloplos elongatus	*Orchomenella sp. 1*	*Tellina bodegensis*
Magelona sacculata	*Pagurus samuelis*	*Tellina carpenteri*
Mediomastus californiensis	*Paleanotus bellis*	*Tellina modesta*
Melita oregonensis	*Paraphoxus spinosus*	
Nephtys caecoides	*Pinnotheres sp. 1*	
Owenia collaris	*Platynereis bicanaliculata*	
Pherusa papillata	*Prionospio cirrifera*	
Pholoe minuta	*Protomedeia zotea*	
Photis brevipes	*Protothaca staminea*	
Polycirrus sp. 1	*Saxidomus giganteus*	
Prionospio malmgreni	*Sphaerosyllis californiensis*	
Scolelepis squamata	*Spiophanes berkeleyorum*	
Spiophanes bombyx	*Tresus capax*	
Tharyx parvus		
Transennella tantilla		

species were slower to recover. Although most of these species were present in collections 12 and 13, their abundance was very low. Even in collection 14 the density of this group was only half that in the first two surveys. Ironically, a typical representative of species group 1 is *Capitella capitata*, which is often considered to be a pollution-tolerant opportunist (Figure 7).

Table IV. Mean Density (N/0.1 m^2) of Species Groups and the Total Benthic Assemblage Within Survey Groups, with Survey and Species Groups Based on Normal and Inverse Numerical Classifications

	Survey Groups				
Species Group	1-2	3-9	10-11	12-13	14
1	473.1	61.8	19.1	64.5	231.2
2	143.0	33.5	114.0	407.2	162.6
3	13.3	45.0	220.8	15.9	12.6
Total Assemblage					
$\bar{x}$ N	637.5	142.4	357.1	500.8	439.4
$\bar{x}$ S	34.9	20.2	23.2	36.6	38.0

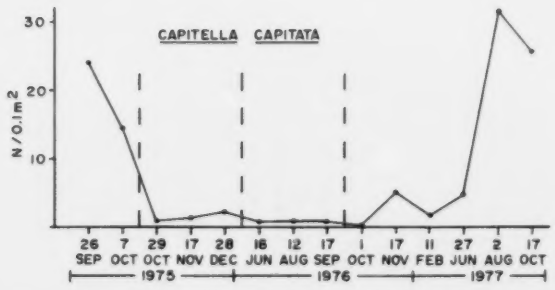

Figure 7. Temporal distribution of *Capitella capitata* at the Yaquina Bay dredge site. Vertical dashed lines represent (in chronological order) the first dredging, presence of R/V Wecoma and second dredging.

Species group 2 recovered more rapidly than group 1 (Table IV). It was the most abundant species group in the intermediate recovery phase (surveys 12–13). Its density decreased in collection 14 to a level close to that observed in the first two collections. The temporal distribution of the clam *Macoma inquinata* is representative of the species in group 2 (Figure 8). After each disturbance, larval recruitment resulted in an increased abundance of *M. inquinata*. Its density decreased after collection 12 to the predredging level.

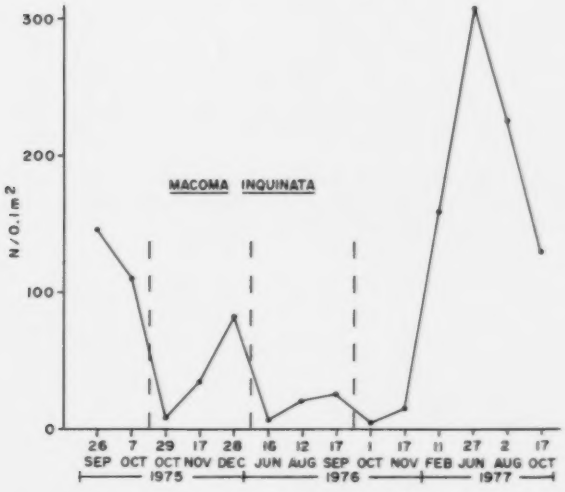

Figure 8. Temporal distribution of *Macoma inquinata* at the Yaquina Bay dredge site. Vertical dashed lines represent (in chronological order) the first dredging, presence of the R/V Wecoma and second dredging.

By contrast to species groups 1 and 2, the abundance of the third group was enhanced during the period when the remainder of the assemblage was adversely affected (surveys 3-9) and especially during the initial phase of recovery (surveys 10-11) (Table IV). Two species within this group represent different patterns of colonization of the disrupted dredge site. Postlarval individuals of the amphipod *Anisogammarus pugettensis* were present in increased numbers after both dredgings, especially the first (Figure 9). This is a very mobile species that was probably attracted by the feeding opportunities created by the disturbance. The polychaete *Armandia brevis* colonized the dredge site through larval recruitment (Figure 10). A very dense population of *A. brevis* was found during surveys 10

and 11 after the second dredging. Both of the species were present, but relatively rare in collections 1-2 and 12-14.

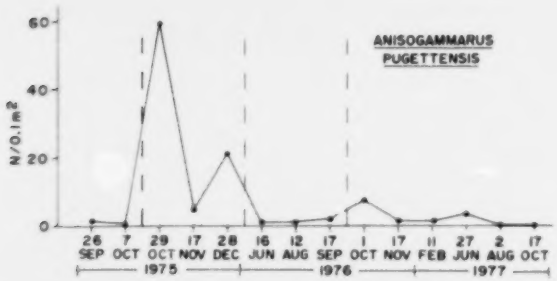

Figure 9. Temporal distribution of *Anisogammarus pugettensis* at the Yaquina Bay dredge site. Vertical dashed lines represent (in chronological order) the first dredging, presence of the R/V Wecoma and second dredging.

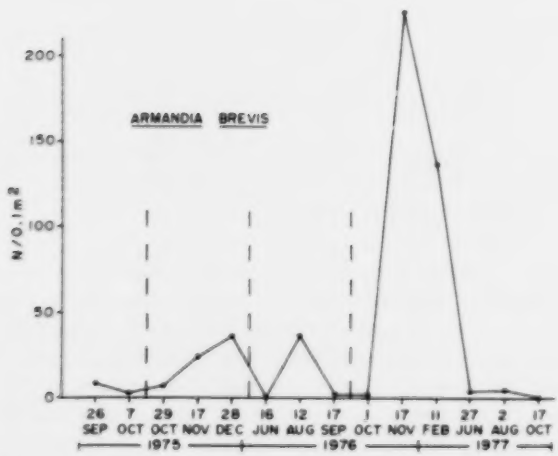

Figure 10. Temporal distribution of *Armandia brevis* at the Yaquina Bay dredge site. Vertical dashed lines represent (in chronological order) the first dredging, presence of the R/V Wecoma and second dredging.

DISCUSSION

The hypothesis that dredging would affect all segments of the macrobenthos and cause reductions in areal species richness and density was confirmed. Richness and density decreased to 52% and 20%, respectively, of their baseline levels immediately after the first dredging. This decline was similar among abundant, common and rare species. The second dredging had a comparable quantitative effect, even though it affected an already impoverished benthic assemblage. One would expect this hypothesis to be confirmed for a disturbance like dredging, which involves the physical removal of benthic sediments and biota. Survival in chemically contaminated sediments may indicate phylogenetic differences in sensitivity to pollution. Bender et al. [9], for example, demonstrated through bioassays that benthic species found on an oiled beach had a greater tolerance to oil than species found only on control beaches.

Our second hypothesis concerned the appearance and dominance of opportunistic species during the early stages of recovery. We observed two patterns in the response of opportunists: adult immigration and larval recruitment. The density of postlarval specimens of the amphipod *Anisogammarus pugettensis* increased immediately after the first dredging and, to a lesser extent, after the second dredging. This species may have been attracted to the feeding opportunities created by the disruption of the seabed. This is supported by the failure of *A. pugettensis* to appear in large numbers after the departure of the R/V Wecoma in June 1976. The exact cause of the degradation of the benthos associated with the presence of this ship is uncertain. The vessel shaded the bottom and its physical presence in the water column increased bottom current velocities. The degree of structural change in the benthic assemblage after the ship left was comparable to that caused by dredging. One difference is that the presence of the ship may not have caused an immediate disturbance that would attract *A. pugettensis* or adults of other mobile species.

The second pattern of opportunistic response involved the larval recruitment of the polychaete *Armandia brevis*. Although the density of this species increased after the first dredging and after the departure of the R/V Wecoma, it was most abundant after the second dredging. Because of the presence of the stress-tolerant polychaete *Capitella capitata* at the survey site before the initial disturbance, we expected it would also be a dominant during the early stages of recolonization. However, the abundance of *C. capitata* dropped sharply after the first dredging and did not return to its predisturbance level until the final stage of recovery of the entire assemblage. The failure of this deposit-feeder to become a dominant during the period of faunal degradation may be attributable to the great reduction in the fine fraction of the sediment after dredging. The reappearance of *C. capitata* was closely related to the redeposition of very fine sands, silts and clays.

Oliver et al [2] also found that the early phase of macrofaunal recovery after dredging and spoil disposal in Monterey Bay and Moss Landing Harbor, California was characterized by the immigration of mobile crustacean adults and the settlement of polychaete larvae. The principal polychaete opportunists at their disturbance sites were *Armandia brevis* and *Capitella capitata*. Their field and laboratory experiments indicated that *C. capitata* had a greater preference for finer sediment and/or calmer water than *A. brevis*. This supports our conclusion that the changes in the density of *C. capitata* were controlled by the proportion of the fine sediment fraction at the Yaquina Bay dredge site.

Indices of diversity and dominance did not follow the pattern suggested by our third hypothesis. These indices generally decreased after each of the three disturbances, but they also equalled or exceeded predredging levels in collections in which areal richness and density were greatly reduced. The large population of *Armandia brevis* established after the second dredging caused a major decline in information-theoretical diversity (H') and in the complement of Simpson's [5] index of dominance. Thus, these indices were relatively high during periods of major faunal degradation and very low during the initial phase of recovery. They provided a misleading indicator of the condition or "health" of the benthos following dredging.

In theory H' represents an integrated measure of the two components of diversity—richness and evenness [6]. The strong correlation in our results between H' and the complement of Simpson's [5] index suggests that the former is determined principally by the degree of dominance exerted by a few species. The distinct differences between the temporal patterns of H' and areal species richness indicate that richness had little influence on the value of H'.

The effectiveness of diversity indices should not be based on a comparison of their behavior following extreme or relatively minor biological perturbations. Kaplan et al. [10] observed a fourfold decrease in H after the near total benthis defaunation of a Long Island, New York dredged channel. Partial defaunation due to maintenance dredging in Coos Bay, Oregon resulted in either no change or a slight increase in H' [11]. Our research and that of Oliver et al [2] examined dredging disturbances intermediate between these extremes. In neither case was there a clear relationship between H' and faunal recovery.

Our fourth hypothesis that the final phase of recovery would involve the disappearance of opportunists and the reestablishment of the predisturbance fauna was confirmed, but recovery was less rapid than we had predicted. After the second dredging in September 1976, *Armandia brevis* dominated the benthos until some time during the spring of 1977. During the following summer and fall, the structure of the community returned both quantitatively and qualitatively to the initial predisturbance state. Faunal recovery was indicated by changes in species composition, density of individuals and the entire assemblage,

and areal species richness. These temporal patterns were very effectively summarized by numerical classification techniques.

Recovery from the second dredging took about one year. We did not anticipate the lasting physical change in sediment composition in our original prediction of a shorter recovery period. The redeposition of the finer sediment fraction was correlated in time with the reestablishment of many species at their predisturbance densities. We do not know whether this correlation reflects a cause or an effect. Specifically, we do not know if the dense population of *Armandia brevis* in any way "conditioned" the sediment and permitted a classical succession during the final phase of faunal recovery.

The rate of recovery of the benthos is dependent on the extent of defaunation and the persistence of physical alterations, especially changes in sediment composition and current patterns. A portion of the benthos often survives dredging and provides a nucleus for the reestablishment of the biota [11]. If defaunation is complete, the initial phase of colonization may be delayed. Reish [12], for example, found no animals for 7 weeks in a new boat basin in Alamitos Bay, California, but species appeared rapidly afterwards and richness reached a plateau within 10 months. Kaplan et al. [10] concluded that the potential for recovery of a dredged estuarine channel was reduced because of long-term changes in current velocities and sediment composition. They found that most initially abundant and common species had not recovered or were still absent 11 months after dredging. At the Yaquina Bay dredge site, the presence of survivors and changes in sediment composition also affected faunal recovery.

The rate of recovery from dredging also varies with the ability of the affected assemblage to adapt to environmental perturbations. Boesch [1] suggested an inverse relationship between species richness and resilience from human disturbance. Although fewer species exist in physically rigorous and unpredictable habitats, they tend to be stress tolerant and well adapted to a fluctuating environment [13]. The disruption of benthic habitats by dredging resembles natural sediment disturbances caused by wave action, currents and siltation. Benthic assemblages living under naturally unstable sediment conditions should therefore be less diverse, but more resilient to dredging than the benthos found in more stable sediments. Oliver et al. [2] confirmed this hypothesis in their comparison of recovery rates of the benthos at dredging sites along natural stress gradients. They found that the assemblages that recovered most rapidly had the least complicated community structure and were dominated by early successional species naturally adapted to physical disturbances. McCauley et al. [11] found that the density of the infauna returned to predisturbance levels within 28 days after maintenance dredging in Coos Bay, Oregon. They also attributed this high resilience to the initial dominance of species with opportunistic life strategies. The benthos at the Yaquina Bay dredge site required a

full year for recovery. In comparison with the Coos Bay study, one would expect the assemblage we examined to be less resilient because of its greater species richness, the absence of strong domination by opportunists, and less frequent exposure to sediment disturbances associated with harbor activities.

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